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ORIGIN AND DISTRIBUTION OF BARTLESVILLE AND BURBANK SHOESTRING OIL SANDS IN PARTS OF OKLAHOMA AND KANSAS[1]

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ABSTRACT

About 2 years have been spent by several members of a United States Geological Survey party in studying the buried oil- and gas-bearing Bartlesville and Burbank sands in Osage and Kay counties, Oklahoma, and Cowley, Butler, and Greenwood counties, Kansas. This work followed about 2½ years study of the Kansas area, made by Bass for the Kansas Geological Survey in coöperation with the United States Geological Survey, the results of which were presented before the Association meeting at Dallas and published in the *Bulletin* in 1934. The later work has also included an examination of the Bluejacket sandstone, which crops out in northeastern Oklahoma and southeastern Kansas, and certain of the beach deposits on the Atlantic coast and on the Gulf coast of Texas.

Stratigraphic cross sections made from well logs show that the Bartlesville sand is stratigraphically lower than the Burbank sand and that the shoestring sands of Greenwood, Butler, and Cowley counties, Kansas, are equivalent to the sands of the Burbank, South Burbank, and Naval Reserve oil fields of Oklahoma. The Bartlesville and Burbank sands are actually zones composed of numerous lenses of sand that occur within narrowly restricted limits in the Cherokee shale.

The Burbank sand bodies particularly occur in definite systems, called "trends," made up of lenses that are separated by gaps containing no sand. The individual sand lenses have an offset arrangement within the trends. Similar features are found in the systems of offshore bars on the Atlantic and Gulf coasts. The shapes in cross section of the shoestring oil-bearing sand bodies are similar to those of offshore bars. The composition and physical characteristics of the oil-bearing Bartlesville and Burbank sands are similar to those of the sands that form the modern offshore bars on the Atlantic and Gulf coasts. Many modern offshore bars, of which that at Cape Henry, on the Virginia coast, is an example, are made up of a series of overlapping beaches that have been preserved as ridges of sand trending parallel with the coast. These ridges represent lines of beach growth. The sand body of the main Burbank oil field, that of the Stanley stringer on its eastern margin, and the sand body of the South Burbank oil field appear to be characterized by features that may be growth ridges.

The studies indicate that the Bartlesville sand was deposited as a series of offshore bars along the western shore of the Cherokee sea during an early stage of the sea when the western shore migrated to and fro across a narrow strip of country in northeastern Oklahoma and southeastern Kansas. The Burbank sand bodies were deposited much later, after the Cherokee sea had expanded widely to the northwest. The trends of Burbank sand were deposited as offshore bars mainly during the Teeter-Quincy and Sallyards-Lamont stages of the Cherokee sea. The sand bodies of the Burbank and South Burbank oil fields are tentatively assigned to the Teeter-Quincy stage and are believed to have been formed by a series of overlapping beach deposits similar to those that form Cape Henry, Virginia.

[1] Read before the Association at the Tulsa meeting, March 20, 1936. Published by permission of the director of the United States Geological Survey. Manuscript received, October 24, 1936.

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It is recommended that, in prospecting for additional shoestring-sand oil fields, drilling sites be selected by projecting the known shoestring-sand trends in approximately straight lines similar to the trends of the systems of offshore bars on our present coasts, and not by meandering lines similar to stream courses. Inasmuch as modern offshore bars and the developed shoestring-sand bodies have an offset or *en échelon* arrangement within the systems and have gaps separating the individual sand bodies, these features should be expected in the projection of the sand trends into undeveloped territory.

INTRODUCTION

The oil- and gas-producing Bartlesville and Burbank sands of Kansas and Oklahoma occur in the lower part of the Cherokee shale (Fig. 5), which in this region is the oldest formation in the Pennsylvanian series. The sands characteristically occur in elongate bodies 50–150 feet thick, ½–2 miles wide, and 2–6 miles long (Fig. 1). These bodies are arranged in belts, some of them more than 50 miles long, to which the name "trends" has been applied.[5] In much of the area adjacent to the trends little or no sand occurs at the horizon of the lenses. Because of their distribution in elongate belts the sands are called "shoestring sands," and the oil pools are known as "shoestring fields." The Bartlesville sand occurs chiefly in eastern Osage County, Oklahoma, and the Burbank sand occurs in western Osage and eastern Kay counties, Oklahoma, and in Cowley, Butler, and Greenwood counties, Kansas. Shoestring-sand bodies occur, however, in a much larger region in eastern Kansas and Oklahoma than is shown in Figure 1.

According to Carpenter[6] oil was discovered in the Bartlesville sand near Bartlesville, Oklahoma, in 1897, and was being produced from this sand in Osage County, in the Boston pool near Cleveland, in the Avant pool near Avant, and near Bartlesville, as early as 1904–1906.[7] Oil fields in the Bartlesville sand were developed intensively in eastern Osage County, Oklahoma, after 1906. Oil was discovered in the Burbank sand in the large Burbank oil field in 1920, and the field was developed during the succeeding few years. Oil fields in Kansas in the Burbank sand (locally called "Bartlesville") were rapidly extended in 1922–1926,[8] although oil had been found there in the Burbank sand

[5] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), p. 1313.

[6] Everett Carpenter, "Oil and Gas in Oklahoma, Washington County, Oklahoma," *Oklahoma Geol. Survey Bull. 40*, Vol. 3 (1930), p. 139.

[7] Everett Carpenter, *op. cit.*, p. 139.
Bess Mills Bullard, "Digest of Oklahoma Oil and Gas Fields," *Oklahoma Geol. Survey Bull. 40*, Vol. 1 (1928), pp. 108, 117, 146.

[8] W. R. Berger, "The Relation Between the Structure and Production in the Sallyards Field, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921), p. 276.

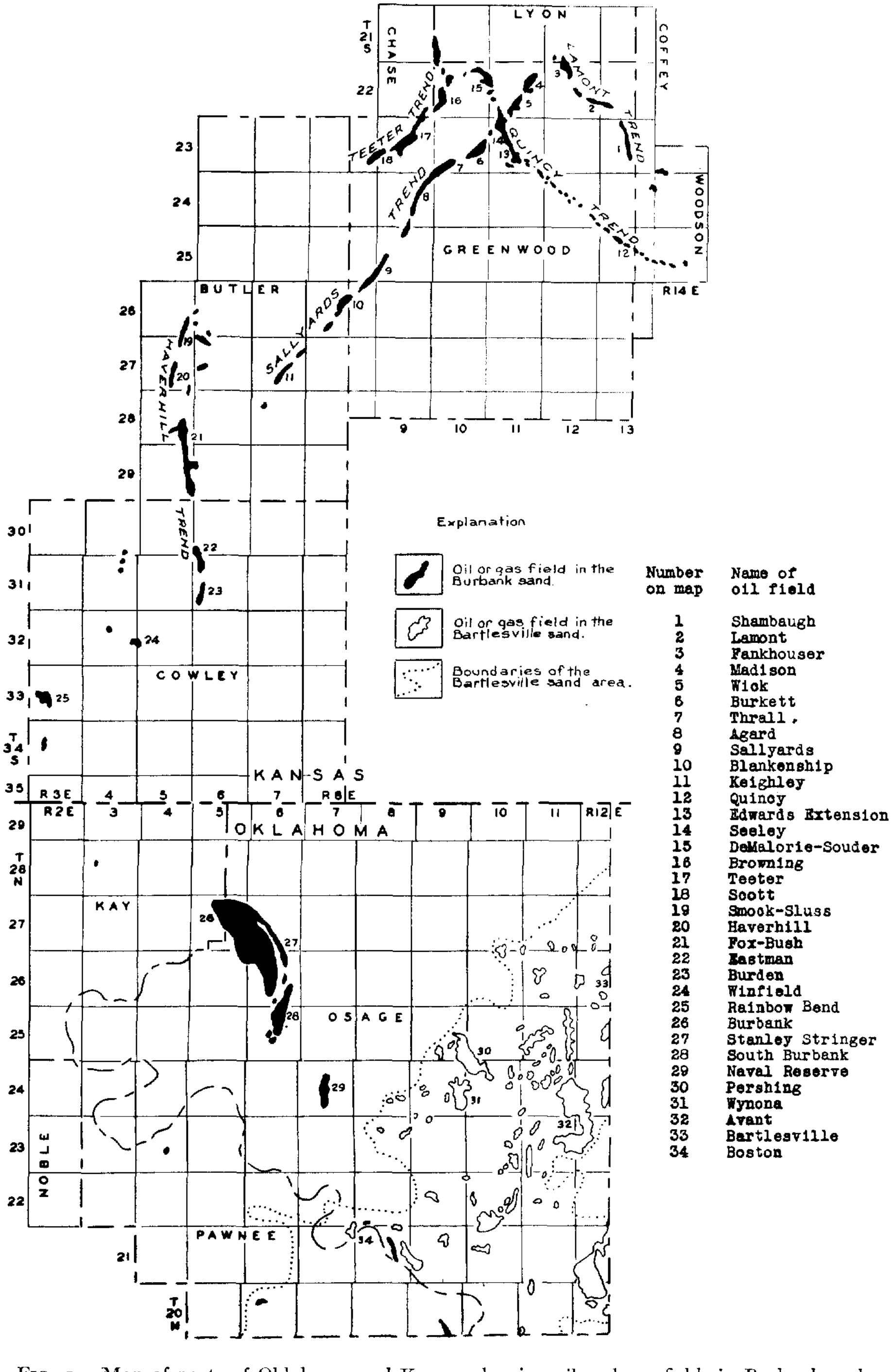

FIG. 1.—Map of parts of Oklahoma and Kansas showing oil and gas fields in Burbank and Bartlesville sands.

as early as 1917.[9] The South Burbank oil field, in western Osage County, Oklahoma, discovered in December, 1933, and still under development, is one of the most productive pools of this type. Its discovery and growth have stimulated new interest in the shoestring-sand region. In most localities in the region the gravity of the oil from the Bartlesville sand is about 31°–34° Baumé, and that from the Burbank sand is approximately 38°–40°. The depths to the sands range from about 1,200 feet in eastern Osage County, Oklahoma, to about 3,000 or 3,300 feet in Kay County, Oklahoma, and western Cowley County, Kansas.

The Burbank field in Osage and Kay counties, Oklahoma, on January 1, 1936, had yielded 188,000,000 barrels of oil, or an average of about 8,160 barrels to the acre. A few leases (160 acres each) in the field had produced more than 20,000 barrels of oil to the acre. In the South Burbank field the high initial yield of the wells, many of which produced 3,000–5,000 barrels of oil a day, and the large thickness of pay sand indicate that the average yield of oil to the acre here will exceed that of the Burbank field. Moreover, the South Burbank oil field is being operated as a unit and a high reservoir pressure is being maintained by returning gas to the sand. This method of operation is believed to be much more efficient than that used in the main Burbank field, and it constitutes an additional reason for the prediction that the ultimate average yield in the South Burbank field will exceed that of the Burbank field. Some leases in the Avant field, in eastern Osage County, Oklahoma, have produced more than 30,000 barrels of oil to the acre from the Bartlesville sand, but the average yield from the Bartlesville sand, in eastern Osage County may not exceed 4,000–6,000 barrels to the acre. Several shoestring fields in Kansas probably will have an ultimate yield of 7,000–8,000 barrels of oil to the acre, but others will yield considerably less. Hutchinson[10] has suggested that the average yield in the shoestring-sand oil fields of Butler and Greenwood counties, Kansas, which according to him occupy 30,000 acres, may be about 6,000 barrels to the acre.

Harve Loomis, "The Burkett-Seeley Pool, Greenwood County, Kansas," *ibid.*, Vol. 7, No. 5 (1923), p. 482.

Everett Carpenter, "Petroleum Development in Kansas During 1924," *Production of Petroleum in 1924, Amer. Inst. Min. Met. Eng.* (1925), pp. 154–55.

Henry Ley, "Oil Resources of Oklahoma and Kansas in 1926," *Petroleum Development and Technology in 1926, Amer. Inst. Min. Met. Eng.* (1927), p. 639.

[9] J. D. Northrop, *U. S. Geol. Survey, Mineral Resources of the United States, 1917*, Pt. 2 (1920), p. 769.

[10] N. M. Hutchinson, "Program of Gas and Air Repressuring in Eastern Kansas Proves Profitable," *Oil and Gas Jour.* (February 27, 1936), p. 33.

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PURPOSE

The chief problem in the study of the Bartlesville and Burbank sands has been to determine the origin of the sand bodies and to apply the findings to the discovery of additional oil fields. The correct interpretation of the origin of the sand deposits is, therefore, not only of scientific interest but of commercial importance. The results of this study can be applied not only to Greenwood, Butler, Cowley, and adjacent counties in Kansas and to Osage and Kay counties in Oklahoma, but to a broad region in northeastern Oklahoma and eastern Kansas and probably to a large region in north-central Texas and to many other localities in the United States where deposits of similar type remain to be exploited for oil. As information has accumulated by the exploration for oil, particularly in Kansas, Oklahoma, and Texas, oil-bearing sand lenses, not wholly unlike the Bartlesville and Burbank sand bodies described here, have been found to be much more numerous and more productive of oil than was earlier believed. There very small dimensions and lack of structural expression at the surface make them difficult to locate, but the high quality of their oil, the longevity of the production from them, and their relatively shallow depth in many localities make their exploitation attractive to the oil producer.

The work of the writers indicates that there are several localities in the area studied (Fig. 1) that probably contain undiscovered shoestring oil fields and that these localities are worthy of intensive but intelligently directed prospecting. Because sandstone beds that originated by any one set of depositional processes form an areal pattern that is quite unlike that of a deposit formed by other processes, the determination of the origin and areal pattern of the Bartlesville and Burbank sand bodies has a practical value in prospecting for new oil pools of the shoestring type. A geologist attempting to extend the shoestring sand trends into undeveloped territory will project one pattern beyond the known oil fields if he believes that the sands were formed by the filling of stream channels but a quite different pattern if he believes that the sand bodies originated as offshore bars similar to the bars on modern coasts.

If the Burbank sand in western Osage County, Oklahoma, and the adjacent region was laid down by an aggrading river, the distribution of the sand might produce a pattern similar to the sketch on the left in Figure 2, in which most of the wells that found Burbank sand have been included within the meandering boundary lines. If the sand bodies in that region were deposited as offshore bars, an interpretation similar to the sketch on the right in Figure 2, in which many of the wells that found Burbank sand have been included within the boundary lines of hypothetical systems of offshore bars, would appear more plausible.

FIELD STUDIES

The shoestring sands in Greenwood and Butler counties, Kansas, were studied by Bass for the Kansas Geological Survey in coöperation with the United States Geological Survey through a period of about 2½ years, beginning in 1930, and the salient facts which led to the conclusion that these sand bodies were deposited as offshore bars were published in this *Bulletin* in 1934.[11] Since that time the work on the shoestring sands has been extended southward by the writers to include Cowley County, Kansas, and Kay and Osage counties, Oklahoma.

During the summer of 1935, Bass, accompanied by H. D. Miser during a part of the time, studied the modern offshore bars on the eastern coast of North Carolina, Virginia, Maryland, Delaware, and New Jersey, shown in part in Figures 3 and 4. The offshore bars on the Gulf coast of Texas, between Port Arthur and the Rio Grande River, were examined by Kennedy and Bass in December, 1935. Aerial photographs of the coasts of many of the Atlantic seaboard states, made recently for the United States Coast and Geodetic Survey, were studied. Some study was made of sand collected from ancient Pleistocene beaches[12] which lie about 40 feet above the present sea-level, on

[11] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1313–45.

[12] C. W. Cooke, "Correlation of Coastal Terraces," *Jour. Geol.*, Vol. 38 (1930), p. 580.

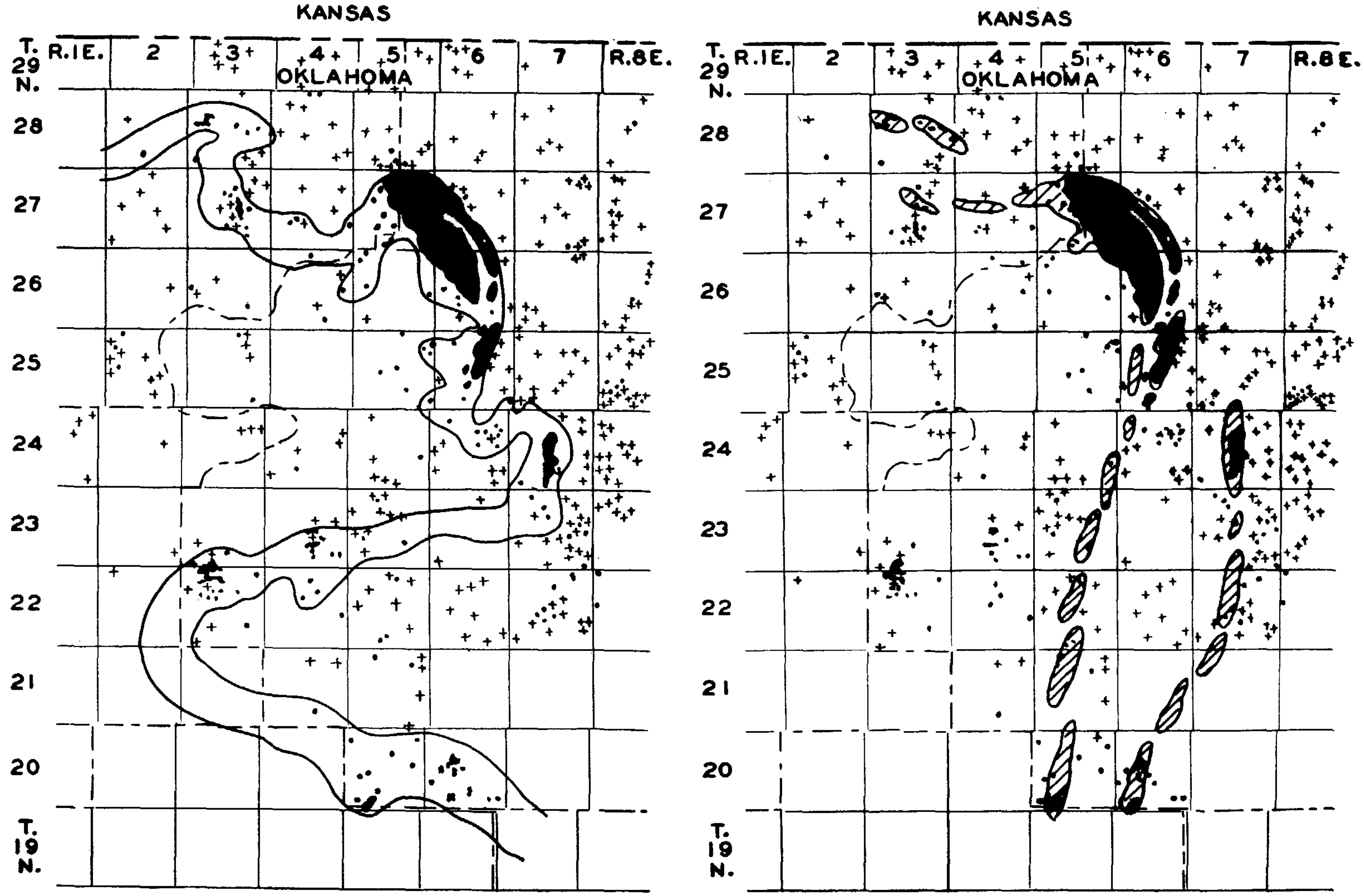

FIG. 2.—Sketch maps of parts of Osage and Kay counties, Oklahoma, showing two possible interpretations of distribution of Burbank sand. *Left:* Meandering boundary lines, similar to the course of a meandering stream, inclose nearly all wells that found Burbank sand. *Right:* Trends of hypothetical offshore bars, patterned after modern coast charts, include most wells that found Burbank sand. Solid black dots and areas indicate wells and fields, respectively, where Burbank sand is present. Plus signs indicate wells in which Burbank sand is absent.

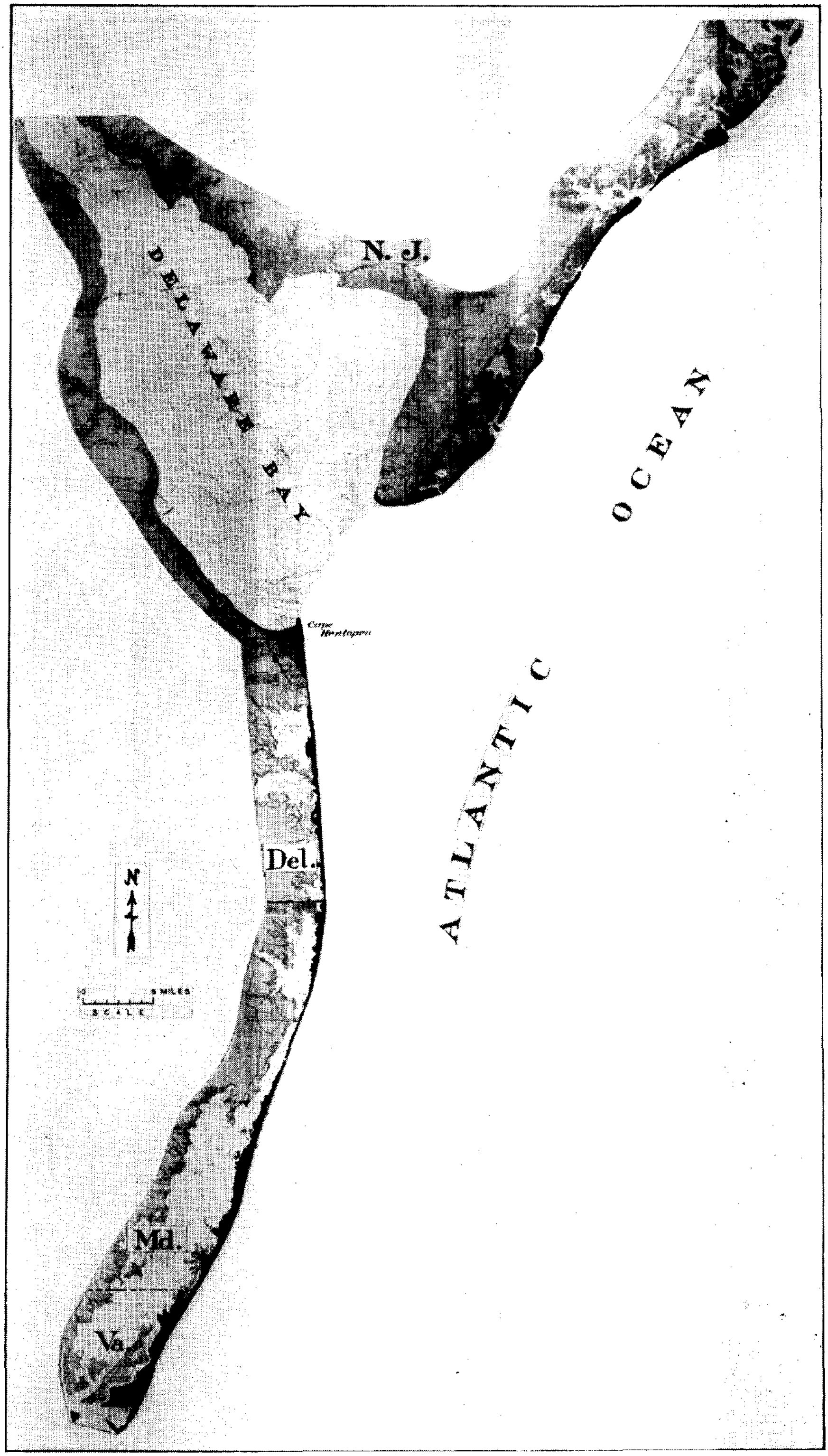

FIG. 3.—Photograph of United States Coast and Geodetic Survey's charts of the Atlantic coast of parts of New Jersey, Delaware, and Maryland. Narrow black areas along coast are off-shore bars; gaps between bars are tidal inlets; shaded areas on landward side of bars are marshes; and irregular-shaped light areas within marshes are lagoons and thoroughfares of open water.

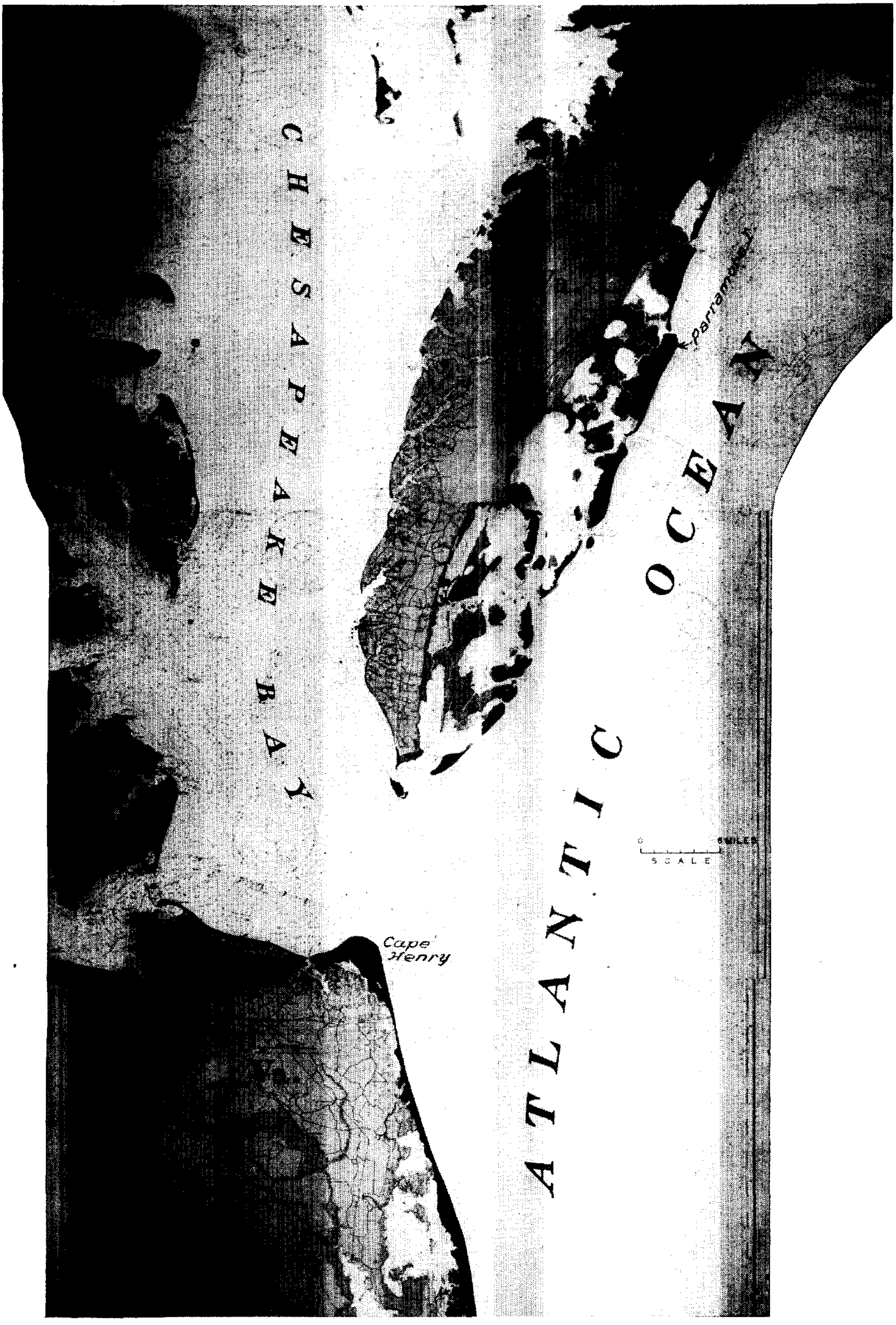

FIG. 4.—Photograph of United States Coast and Geodetic Survey's charts of the Atlantic coast of parts of Virginia. Narrow black areas along coast are offshore bars; gaps between bars are tidal inlets; shaded areas on landward side of bars are marshes; and irregular-shaped light areas within marshes are lagoons and thoroughfares of open water.

the west shore of the Dismal Swamp, in southern Virginia and northern North Carolina.

Very recently the Bluejacket sandstone, shown in Figure 7, has been studied by the writers at numerous localities between Inola, Oklahoma, and Columbus, Kansas. Inasmuch as the Bluejacket sandstone appears to be approximately equivalent to a part of the Bartlesville sand, characteristics revealed by it on the outcrops are believed to be significant in the interpretation of the buried sand bodies.

Drill cuttings of the Bartlesville and Burbank sands from about 700 wells in the area shown in Figure 1 and from a few localities in Washington and Nowata counties, Oklahoma, and cores of the sands in the Madison, Edwards Extension, and Quincy oil fields in Greenwood County, the Haverhill field in Butler County, and the Rainbow Bend field in Cowley County, Kansas, and the Burbank, South Burbank, Pershing, and Avant oil fields in Osage county and the Coodys Bluff, Delaware Childers, and Alluwe oil fields in Nowata County, Oklahoma, were examined microscopically, chiefly by Miss Leatherock, in 1934 and 1935. The microscopic study included also examination of outcrop samples from the Moberly, Warrensburg, and Aurora channel sandstones of Missouri and the Bluejacket sandstone in southeastern Kansas and northeastern Oklahoma. Samples of beach sands from the barrier beaches in Virginia, North Carolina, and Texas and from the Pleistocene beaches in the vicinity of the Dismal Swamp of Virginia were examined microscopically, and comparisons were made with the channel sandstones of Missouri and the Bartlesville and Burbank sands from wells in Kansas and Oklahoma. More than 140 thin sections, made from cores of sand from producing wells and from the outcrop samples, were studied with a petrographic microscope. The details of the microscopic study are described by Miss Leatherock[13] in a separate paper, but the general results of her study are incorporated here.

STRATIGRAPHIC POSITION OF SHOESTRING SANDS

The shoestring-sand bodies of eastern Osage County, Oklahoma, and the southeasternmost part of Kansas belong to the Bartlesville sand in the Cherokee shale, and those of western Osage County and eastern Kay County, Oklahoma, and Cowley, Greenwood, and Butler counties, Kansas, belong to the Burbank sand, which is 50–100 feet stratigraphically above the horizon of the Bartlesville sand. The Red Fork sand of southern and southeastern Osage County, Oklahoma,

[13] Constance Leatherock, "Physical Characteristics of Bartlesville and Burbank Sands in Northeastern Oklahoma and Southeastern Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 2 (February, 1937).

appears to occur approximately at the horizon of the Burbank sand. These conclusions were derived by the preparation of several cross sections, based on well logs, across Osage County and the adjacent areas (Fig. 5) and agree with conclusions reached some years ago by Weirich,[14] McCoy,[15] Berger,[16] and others.

The Bartlesville and Burbank sands are best described as zones because the data show that each of these sands consist of a series of lenses that occur within narrowly restricted parts of the Cherokee shale. For instance, a body of sand near the southeast corner of Osage County, Oklahoma, is not believed to be the exact equivalent of the oil-bearing sand body of the Pershing oil field, in east-central Osage County, 25 miles away. However, the sand in each of these localities is called "Bartlesville" because each occurs somewhere in a zone, 150–200 feet thick, in the lower half of the Cherokee shale, which contains the Bartlesville sand near Bartlesville, the type locality. In the Greenwood-Butler-County region of Kansas the Sallyards and Lamont sand trends are believed to be somewhat younger than the Teeter and Quincy sand trends, but all are called "Burbank sand" because they occur within a narrowly restricted zone that occupies approximately the same stratigraphic position as the Burbank sand in the Burbank oil field of Oklahoma. The cross section in Figure 5 shows the true relation of the Bartlesville sand with respect to the Burbank sand but fails to show the local lenticular features that characterize each of the sands. If the scale of the section were greatly enlarged and additional wells were used, each sand would appear as a series of thick lenses separated by areas containing no sand.

Study of the Bluejacket sandstone on its outcrops in northeastern Oklahoma and southeastern Kansas and of logs of wells in Washington and Nowata counties, Oklahoma, showed its stratigraphic position to be within the Bartlesville sand. This correlation agrees with that made by Snider[17] many years ago.

DISTRIBUTION OF SHOESTRING SANDS

The areal distribution of the Burbank sand trends in Greenwood and Butler counties, Kansas (Fig. 1), and their similarity to the belts

[14] T. E. Weirich, "The Burbank Sand of Kansas and Oklahoma," *Oil Weekly*, Vol. 66, No. 10 (August 22, 1932), pp. 25–28.

[15] Alex. W. McCoy, oral communication.

———, "A Short Sketch of the Paleogeography and Historical Geology of the Mid-Continent Oil District and Its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (September–October, 1921), p. 561.

[16] F. C. Greene, "A Contribution to the Geology of Eastern Osage County," discussion by W. R. Berger, *ibid.*, Vol. 2 (1918), p. 123.

[17] L. C. Snider, *Petroleum and Natural Gas in Oklahoma*, The Harlow-Ratliff Company (1913), p. 46.

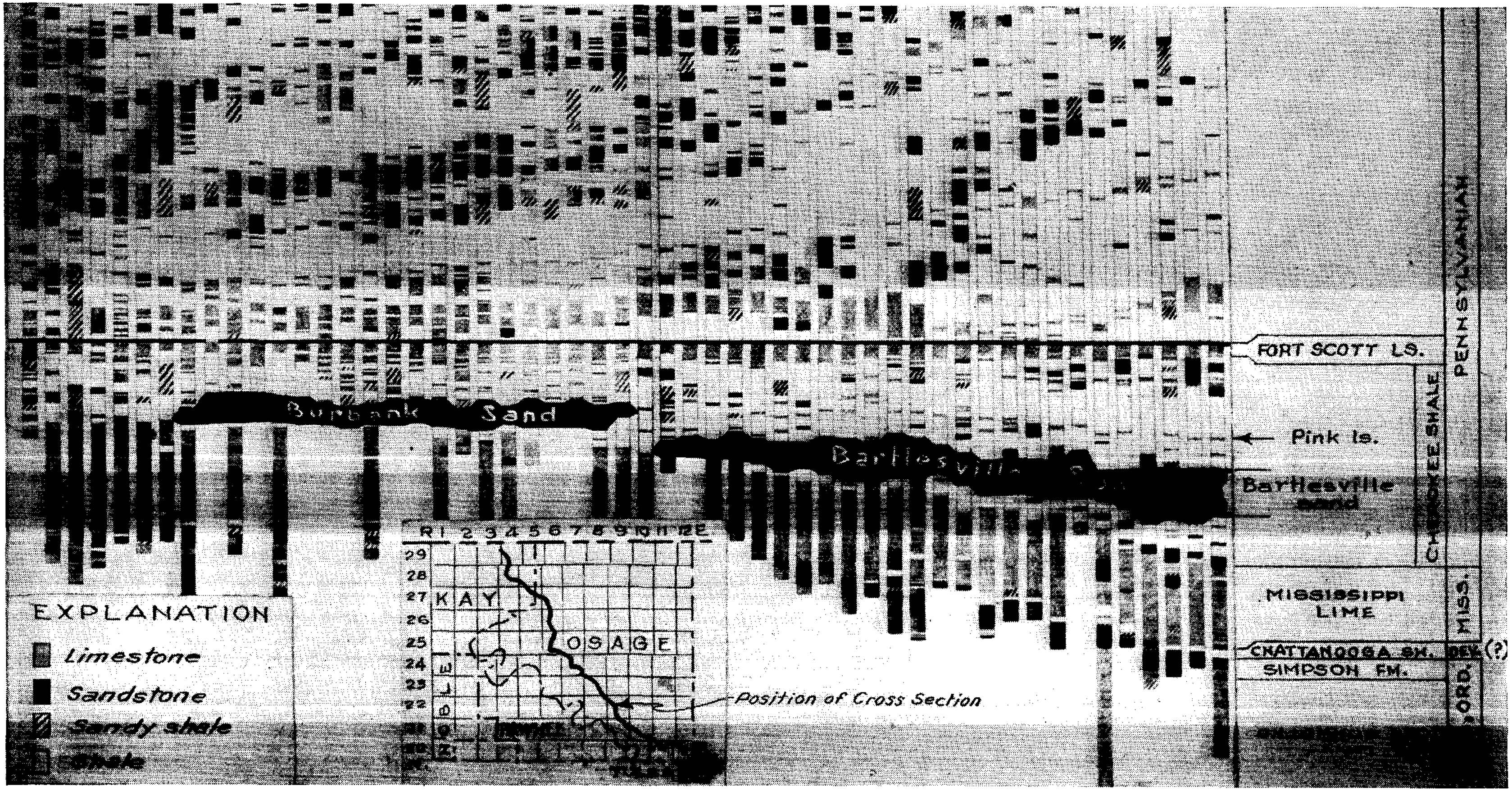

FIG. 5. Northwest-southeast geologic cross section across Osage County and part of Kay County, Oklahoma. Well logs are aligned on top of Fort Scott limestone (Oswego lime).

of offshore bars on modern coasts were described in an earlier paper.[18] A sketch of the offshore bars along a part of the New Jersey coast, placed beside a sketch of the Sallyards and Lamont shoestring-sand trends, which is reproduced in Figure 10 of that paper, shows many strikingly similar features of the distribution of the shoestring-sand bodies and the modern offshore bars. Coast charts showing the offshore bars and other features of a part of the Atlantic coast are reproduced in Figures 3 and 4 of the present paper. The sand bodies of the shoestring trends and those of the modern offshore-bar systems are arranged approximately end to end in belts that have remarkably straight courses; each deviates from straight courses only by broad sweeping curves. The offshore bars of the New Jersey coast are separated by gaps known as tidal inlets; the continuity of each of the shoestring trends is likewise broken by gaps barren of thick beds of sand at the horizon of the shoestring-sand bodies.

Because the Burbank shoestring-sand trends in southern Cowley County, Kansas, and Kay and Osage counties, Oklahoma, have not been so completely revealed by wells as they have in the more fully developed area adjacent on the north, their known distribution in the southern area is less indicative of their mode of origin. The lack of data of this type is offset, however, by information concerning the shapes of the sand bodies of the Burbank, Stanley Stringer, and South Burbank fields, which are similar to those of modern offshore bars. Moreover, if hypothetical sand bodies similar to those known in Greenwood, Butler, and northern Cowley counties, Kansas, are projected across the broad area between the shoestring fields in northern Cowley County, Kansas, and the Burbank field in Oklahoma, the distribution of all these sand bodies and those of the Burbank, Stanley Stringer, and South Burbank fields harmonizes perfectly with modern coast features.

Information about the distribution of the Bartlesville sand is less definite than that for the Burbank sand, because most of the wells in eastern Osage County, Oklahoma, where the Bartlesville sand occurs, were drilled at least 20 years ago, before it was customary to distinguish sand, sandy shale, and broken sand in the well records and before it was common practice to make detailed well logs. Microscopic examinations of well cuttings has shown that sandy shale is recorded as sand at the horizon of the Bartlesville sand in some wells, and it appears reasonable to conclude that probably such records were made

[18] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1326–31.

for many wells drilled in this region many years ago. A map prepared largely by Dillard,[19] after examining all available logs of wells in Osage County, Oklahoma, shows that the Bartlesville sand is absent in many local areas between Bartlesville sand oil pools. A rapid reconnaissance of the outcrops and a study of well records appear to show that the Bluejacket sandstone, which is equivalent to a part of the Bartlesville sand, occurs as northeast and southwest elongate, lens-shaped bodies. Moreover, the oil pools in the Bartlesville sand in eastern Osage County occur as narrow, northeast-southwest elongate areas and form an areal pattern similar to that of the Burbank sand pools, except that the belts formed by the Bartlesville pools are less widely separated and the boundaries are not so sharply defined. All these facts, together with many features of the composition and physical character of the sands, suggest that the Bartlesville sand and the Bluejacket sandstone were deposited under an environment and by processes similar to those that prevailed during the deposition of the Burbank sand, but at a much earlier time.

OFFSET ARRANGEMENT OF SAND BODIES

Modern offshore bars commonly have an offset or *en échelon* arrangement that is produced by a combination of forces, the principal one of which is the action of the longshore currents,[20] which constantly move sand lengthwise of the bars and thus extend the bars by making additions at their ends. This method of growth produces an offset arrangement in the sand bars. These offset features are particularly well developed along the south shore of Long Island, where there is a westward longshore current.[21] The west ends of the bars here are being built out westward. The sand bodies in the Sallyards and Teeter trends in Greenwood and Butler counties, Kansas, have the offset relation of adjacent sand bodies remarkably well developed. With only two exceptions, the north end of each sand body is offset westward with respect to its neighboring sand body. It appears probable that the north end of the sand body of the South Burbank oil field is offset eastward with respect to the south end of the Stanley Stringer and that a narrow area essentially devoid of good sand sepa-

[19] N. W. Bass, L. E. Kennedy, W. R. Dillard, and Constance Leatherock, "Subsurface Geology of Osage County, Oklahoma," *U. S. Dept. Interior Press Mem. 105368* (January, 1936), Plate 3B.

[20] D. W. Johnson, *Shore Processes and Shoreline Development* (1919), pp. 307–08, 370.
F. P. Gulliver, "Shoreline Topography," *Proc. Amer. Acad. Arts and Sci.*, Vol. 34 (1899), pp. 178–79, 234–37.

[21] D. W. Johnson, *op. cit.*, p. 370.
N. W. Bass, *op. cit.*, p. 1332, Fig. 11.

rates the two. The drilling of additional wells will disclose the true relations here.

GROWTH RIDGES IN OFFSHORE BARS AND IN OIL SANDS

Many of the offshore bars on the Atlantic coast are characterized by ridges of sand that trend parallel with the shore. In most localities the ridges are capped by dunes and are separated by long marshy strips or "slashes." These features, which are known as "growth ridges,"[22] are produced by the addition of sand to the seaward side of the bars. In other localities[23] the ocean may be destroying the offshore bars on the seaward side and pushing them landward over the marshes that lie behind the bars. Bogue Bank, on the coast of North Carolina, and Parramore Island, on the Virginia coast, illustrate offshore bars that have been extended seaward by overlapping beach deposits. An aerial photograph of Parramore Island, whose location is indicated in Figure 4, is shown in Figure 8.

Growth ridges are particularly prominent in the offshore bars that form capes near the entrance to large bays, such as Chesapeake Bay (Fig. 4) and Delaware Bay (Fig. 3). Cape Henry, Virginia, on Chesapeake Bay (Fig. 12), is a typical example of a broad bar that shows distinct growth ridges produced by growth of the bar seaward and northward into the bay mouth. Cape Henlopen, Delaware, at the mouth of Delaware Bay, was formed in a similar manner and has similar growth ridges.

The sand body of the Burbank oil field contains ridges that appear to represent growth features. On a map (Fig. 13) showing the thickness of the Burbank sand as recorded in the drillers' logs, prepared by H. B. Goodrich for the United States Geological Survey, the writers have indicated in black all areas where the sand is more than 70 feet thick. In the northernmost part of the field, where the maximum thickness of the sand does not reach 70 feet, a few areas where it is more than 60 feet thick are also shown in black. Inspection of this map shows that there are several narrow, elongate areas of thick sand, or ridges of sand, that have approximately parallel northwest courses.

[22] F. P. Gulliver, *op. cit.*, p. 183.
W. M. Davis, "Geographical Essays," edited by D. W. Johnson (1909), pp. 708–09.
D. W. Johnson, *op. cit.*, pp. 404–53.

[23] E. I. Brown, and others, "Beach Erosion at Folly Beach, South Carolina," *House Document No. 156, 74th Congress 1st Session* (1935).
W. J. Barden, "Wrightsville Beach, North Carolina," *House Document No. 218 73rd Congress 2nd Session* (1934).
F. P. Gulliver, *op. cit.*, pp. 184–85.
W. M. Davis, *op. cit.*, p. 709.
D. W. Johnson, *op. cit.*, p. 389.

They swing westward in the northern part of the field, much as the ridges on Cape Henry swing westward parallel with the south shore of Chesapeake Bay. Several dry holes that found no Burbank sand establish the fact that the sand body lenses out abruptly northward and its north margin is sharply defined. This abrupt termination of the sand body is what might be expected where strong currents surge in and out of a bay. It is comparable in this respect to the north beach of Cape Henry, which has a much steeper slope than the beaches on the Atlantic shore; the steepness presumably is caused by the strong currents that sweep in and out of the mouth of Chesapeake Bay.

In several localities on the Atlantic coast a long, narrow sand bar projects from the end of a much larger body of sand and trends away from the large body at a low angle, much as the Stanley Stringer sand body projects southeastward from the north end of the large sand body of the Burbank field (Fig. 14). A similar sand bar trends southeastward from Cape Henlopen, and a series of bars parallel with the east shore of Cape Cod (Fig. 14) almost duplicates the sand bodies of the Stanley Stringer and South Burbank fields. These long, narrow sand bars were built by the waves and currents later than the large sand bodies which they join.[24] The longshore currents sweep sand along the bars and attempt to extend the bars across the bay mouths,[25] but the currents that sweep in and out of the bays retard the extension of the bars, crowd the bars together at the bay mouths, and turn them landward up the bay shores. All these features appear to be common to the sand bodies at the bay mouths on the Atlantic coast and to the sand body of the Burbank oil field.

SHAPES OF SAND BODIES

It is well known that a stream channel when filled with sand imparts to the resulting deposit a valley-shaped base and a top that is wider than the lower part. On the other hand, an offshore bar is built on a nearly flat surface that has a slight slope seaward, and the top of the bar is convex upward; the lower part of the sand bar is wider than the upper part. Many cross sections of the sand bodies in Greenwood and Butler counties, Kansas,[26] show that the sand bodies there are bar-shaped in cross section; that is, their bases are approximately flat and their tops are convex upward. The cross sections show

[24] W. M. Davis, *op. cit.*, pp. 710–17.

[25] N. S. Shaler, "The Geological History of Harbors," *U. S. Geol. Survey 13th Ann. Rept.*, Pt. 2 (1893), p. 127.

[26] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1322–23, Figs. 4, 6, 7, and 8.

also that the sand bodies with northeast-southwest trends in Kansas were deposited on a base that sloped southeastward and that those with northwest-southeast trends were deposited on a base that sloped slightly southwestward.

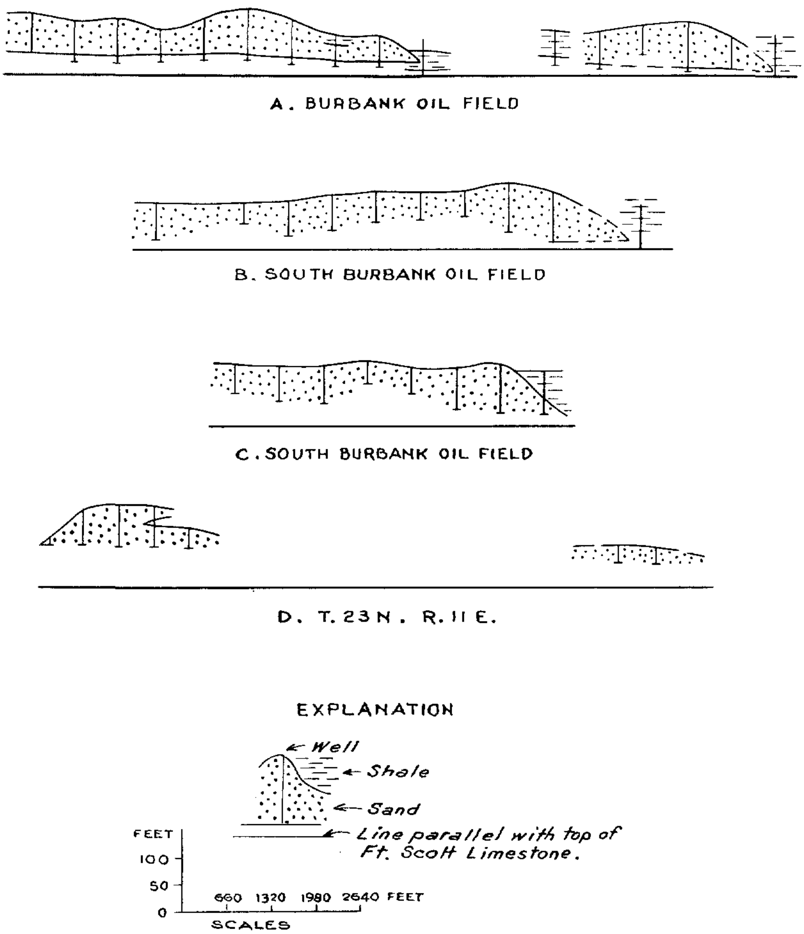

FIG. 6. Cross sections of Burbank and Bartlesville sand bodies based on well logs aligned on top of Fort Scott limestone (Oswego lime). *A*. Burbank sand in Burbank oil field and Stanley stringer, from NW. cor. of SW. ¼ of Sec. 29 east to NE. cor. of NW. ¼, SW. ¼ of Sec. 27, T. 27 N., R. 6 E. *B*. Burbank sand in South Burbank oil field, from SE. cor. of SW. ¼, NE. ¼ of Sec. 9 east to SW. cor. of NW. ¼ of Sec. 11, T. 25 N., R. 6 E. *C*. Burbank sand in South Burbank oil field, from NE. cor. of SE. ¼ of Sec. 9, east to NW. cor. of NE. ¼, SE. ¼ of Sec. 10, T. 25 N., R. 6 E. *D*. Bartlesville sand from center of SW. ¼ east to center of W. ½, SE. ¼ of Sec. 8, thence southeast to north line of SE. ¼, SW. ¼ of Sec. 16, T. 23 N., R. 11 E.

Many cross sections, one of which is shown in Figure 6, were made from logs of wells in the eastern part of the Burbank oil field and in the Stanley Stringer, which forms the easternmost part of the Burbank field in Osage County, Oklahoma, aligned with respect to the top of the Fort Scott limestone. The cross sections show that the upper part of the sand body of the main Burbank field is narrower than the lower part and that it thins toward the eastern margin of the field; they show also that the sand lens of the Stanley Stringer is shaped like an offshore bar. It is particularly significant that most of the cross sections show that the base of the Burbank sand occurs at an increasingly greater interval below the Fort Scott limestone from west to east across the oil field. Therefore, if it is assumed that the top of the Fort Scott limestone formed a horizontal plane when deposited, it is logical to conclude that the Burbank sand was deposited on a surface that had a low slope eastward, similar in general to the slopes of the near-shore bottoms of present seas. The original eastward slope of the sand body is one of the chief facts which indicates that the Cherokee sea lay east rather than west of the Burbank field.

Cross sections of the sand body of the South Burbank field fail to show the shape of the base of the sand, because so few well logs identify the base, but many cross sections, two of which are reproduced in Figure 6, show that the upper surface of the sand body is convex upward, like the surface of an offshore bar, that the crest of the bar is near the eastern margin of the sand body, and that the slope of the top of the sand eastward from the crest is much steeper and more abrupt than the slope westward.

Few data of this character could be compiled for the Bartlesville sand in eastern Osage County, Oklahoma, because many logs of wells outside the oil fields record the Bartlesville sand to be fully as thick there as within the oil fields. However, the data are sufficient to show that the Bartlesville sand occurs as thick lenses, many of which trend northeast-southwest. Throughout eastern Osage County east-west cross sections through Bartlesville sand oil pools show that the lower part of the sand extends farther east than the upper part, and the sand appears to occur slightly lower in the Cherokee shale in the eastern part of a given township than in the western part (Fig. 6D). This fact suggests that a Bartlesville sand body is like a Burbank sand body in that the upper part of the sand body is narrower than the lower part and the sand was probably deposited on a base that sloped eastward.

The Bluejacket sandstone, which is believed to be equivalent to a part of the Bartlesville sand, is as thick as 75 feet in places on the outcrop in northwestern Mayes County, Oklahoma, but is only 10–15 feet thick and locally absent a short distance west of the outcrop, where the horizon of the sand has been penetrated in wells. A sandstone at least 35 feet thick, which Pierce[27] states is the Bluejacket sandstone, crops out near Columbus, Kansas, which is about 60 miles northeast of the northeastern corner of Osage County, Oklahoma. The sandstone is absent a few miles northwest of the outcrops, where beds at its horizon have been penetrated by many core-drill holes.[28] These facts indicate that the Bluejacket sandstone consists of thick northeast-southwest elongate lenses whose easternmost parts have been destroyed by erosion. The data available to the writers are insufficient to indicate the details of the shapes of the lenses in cross sections.

COMPOSITION AND PHYSICAL CHARACTER

The elongate lens-shaped shoestring-sand bodies of the Burbank and Bartlesville sands range in thickness from 25 or less to more than 150 feet. Cores and well cuttings of these sands show that in some fields the sand is composed of fairly homogeneous material throughout thicknesses of more than 50 feet. The Bartlesville and Burbank sands are not everywhere solid bodies, however, but consist of thick beds of sand separated by thin beds of shale, sandy shale, and rarely limestone. Characteristically the thicker parts of sand bodies contain fewer partings of shale and sandy shale. As a rule, sand bodies contain more partings near their margins than near their middles. A few cores showed that the thick beds of sand are locally cross-bedded at angles of 10° or less; most cores reveal horizontal beds.

Bedding planes are not discernible in many cores of the main massive parts of the sand bodies. These thick homogeneous parts of the sands, however, are locally associated with beds of finely laminated sand and sandy shale, in which the quartz, mica, and other minerals and the carbonaceous material are segregated into fine laminae that are sharply defined. The finely laminated beds appear to contain much more carbonaceous material and mica than the massive homogeneous beds.

A zone of dense siltstone or very fine-grained sandstone forms the uppermost part of the sand bodies in most localities. Sandy shale containing thin beds of coaly shale and lenticular coal beds occur immediately above the sand in many localities and are in turn commonly overlain by beds of fossiliferous limestone. The record of a core from the uppermost part of the Bartlesville sand in the Pershing oil field

[27] W. G. Pierce, Map showing Geologic Structure of Southeastern Kansas Coal Fields and the Kansas Zinc-Lead District, *U. S. Geol. Survey* (1935).

[28] W. G. Pierce, oral communication.

of east-central Osage County, Oklahoma, shown in Figure 16, is typical of the varied character of the beds that make up the sand bodies in many localities.

A clean exposure of the Bluejacket sandstone in northwestern Mayes County, Oklahoma, shows it to be composed of thick beds of

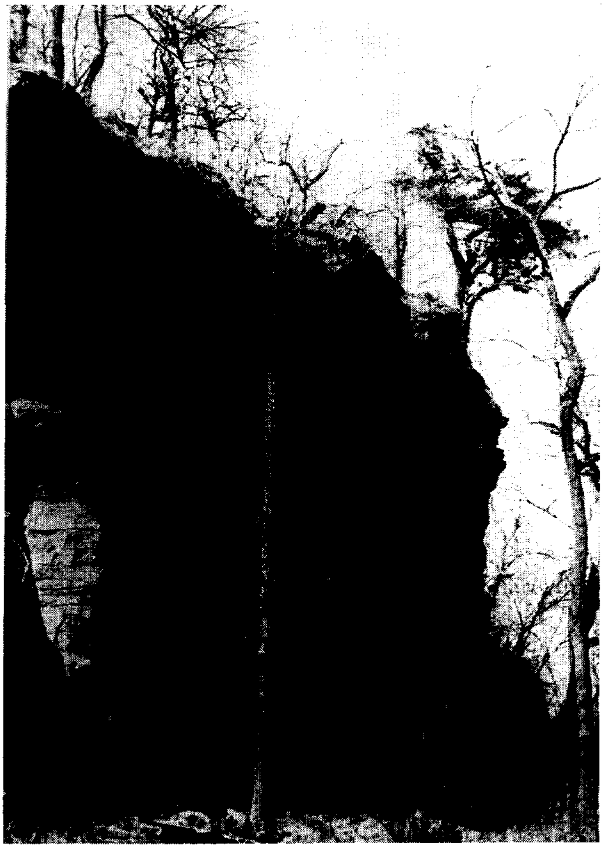

FIG. 7. Bluejacket sandstone (equivalent to part of Bartlesville sand) in SE. ¼ of Sec. 8, T. 21 N., R. 18 E., 5 miles west of Pryor, Oklahoma.

homogeneous sand containing no partings throughout a thickness of 66 feet. It is almost continuously exposed for 1,000 feet westward from this locality and in that distance thins to half its maximum thickness but maintains its massive character and homogeneous composition. Exposures elsewhere in the region reveal massive Bluejacket sandstone locally as thick as 50–60 feet. The true bedding and cross-bed-

FIG. 8. Aerial photograph of northeastern part of Parramore Island, Wachapreague Inlet, and southeastern tip of Cedar Island, Virginia. (By U. S. Army Air Corps.) Beach-growth ridges are covered with vegetation and show as dark bands, some of which trend parallel with the shore and others more northeasterly than the shore. Narrow white area bordering ocean is barren sand beach.

ding seen in the outcrops of Bluejacket sandstone (Figs. 7, 9, and 11) in northeastern Oklahoma and southeastern Kansas are in general

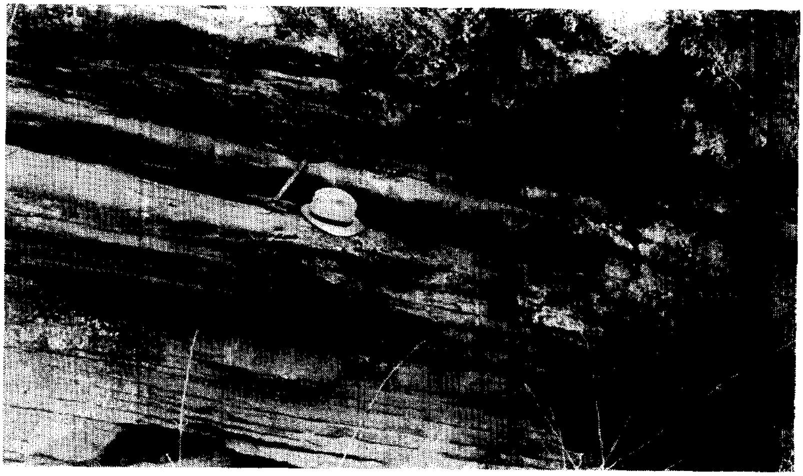

FIG. 9. Thin-bedded Bluejacket sandstone in SE. ¼ of Sec. 8, T. 21 N., R. 18 E., 5 miles west of Pryor, Oklahoma. Angle of dip of beds is accentuated by slight slump of sandstone block.

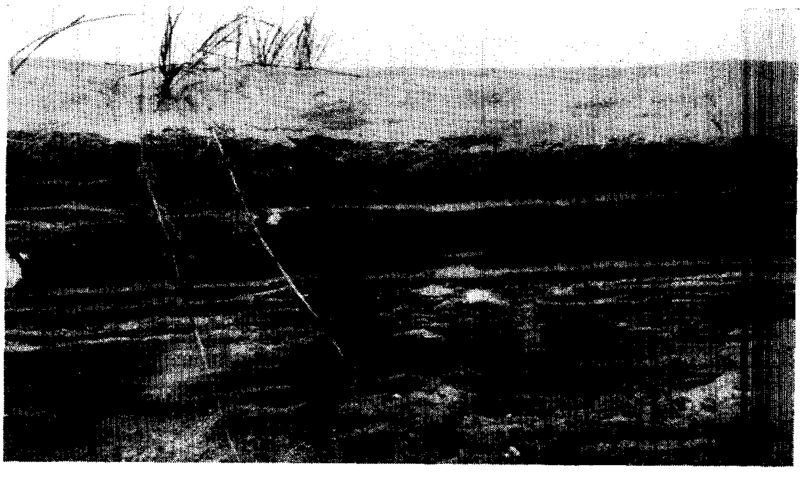

FIG. 10. Bedding in Recent offshore bar at Indian River inlet near Rehoboth Beach, Delaware.

similar to the bedding in the recently formed beach deposits on the Atlantic coast (Fig. 10).

The Bartlesville and Burbank sands are very similar in composition and physical character. They are composed mainly of quartz grains, commonly showing new quartz growth, loosely cemented by a mixture of magnesium, iron, and calcium carbonate and locally by silica, dolomite, or calcite. In addition to quartz the sand contains about 1 per cent of mica; traces of feldspar, zircon, chlorite, glauconite, hornblende, rutile, magnetite, pyrite, and epidote; 10–20 per cent of detrital rock fragments (chert, shale, and schist), and a trace to 10 per cent of carbonaceous material. The modern beach sands are composed essentially of the same minerals that are found in the buried oil sands. Locally the oil sands contain much altered magnetite in the

FIG. 11. Cross-bedded Bluejacket sandstone in SE. ¼ of Sec. 8, T. 21 N., R. 18 E., Oklahoma.

form of minute siderite concretions concentrated in laminae. Black sand composed mainly of ilmenite but containing magnetite is commonly concentrated in layers in the modern beach sands.[29]

The sand grains in the oil sands and in the Bluejacket sandstone are well sorted throughout the sand bodies. Recently formed beach sands are characteristically well sorted. The Bartlesville and Burbank sands in most localities are predominantly fine-grained but locally contain a large number of medium and coarse grains and a few very coarse grains. The sand in most localities contains 10 per cent of silt and clay but locally as little as 5 or as much as 40 per cent. In general the beach sands examined contained much less silt and clay than the oil sands. However, the sand from the Pleistocene beaches near the Dismal

[29] J. H. C. Martens, "Beach Sands between Charleston, South Carolina, and Miami, Florida," *Bull. Geol. Soc. America*, Vol. 46 (1935), pp. 1576–80.

Swamp in Virginia contained as much silt and clay as most of the oil sands examined. Sand obtained near Wilmington, North Carolina, from the wall of a canal cut through an old offshore bar that is now surrounded by marshes, has a high content of carbonaceous material. Offshore bars along the coast of Brazil are tightly cemented with calcium carbonate, which, according to Branner,[30] was introduced into the beach sand by waters from the lagoons. These facts suggest that although many of the very fine particles that are found in the Bartlesville and Burbank sands, such as silt and clay and the finely divided carbonaceous material, probably were deposited contemporaneously with the associated coarser sand grains, some of them may have been introduced into the beach sands chemically by precipitation from percolating water and some mechanically by settling out of muddy lagoon water that filtered through the sand subsequent to its deposition.

Rounded chunks of shale were found in the Bartlesville sand in a core from the Pershing oil field in Osage County, Oklahoma, and in the Bluejacket sandstone[31] at the outcrop near Columbus, in southeastern Kansas, and have been reported from wells in the Burbank sand in Greenwood County, Kansas. Some Mid-Continent geologists[32] have suggested that the occurrence of clay balls in the oil sands is strong evidence indicating that the sands originated as stream deposits, and in support of their contention they have cited the not uncommon occurrence of clay balls in stream courses, particularly those of the semi-arid country of the western states. As pointed out by Gardner[33] and other geologists, there appears to be little doubt that some concretions found in sedimentary rocks were formed as clay balls by stream currents. According to Grabau,[34] however, "clay boulders formed of plastic clay rolled about by waves are not uncommon occurrences on the seashore" and when incorporated in sediments should have the appearance of concretions. Grabau noted the occurrence of clay boulders on the coast of Scotland and cited occurrences on the coast of the Red Sea observed by other geologists. Haas[35] described spheroidal and ellipsoidal clay balls on the beach of Lake

[30] J. C. Branner, "Stone Reefs on the Northeast Coast of Brazil," *Bull. Geol. Soc. America*, Vol. 16 (1904), pp. 1–12.

[31] Locality shown to the writers by W. G. Pierce, U. S. Geol. Survey.

[32] Oral communications.

[33] J. H. Gardner, "Physical Origin of Certain Concretions," *Jour. Geol.*, Vol. 16 (1908), pp. 452–58.

[34] A. W. Grabau, *Principles of Stratigraphy* (1924), p. 711.

[35] W. H. Haas, "Formation of Clay Balls," *Jour. Geol.*, Vol. 35, No. 2 (1927), p. 150.

Michigan. Rounded clay balls composed of the same materials as the adjacent marsh muck were observed in the beach deposits on the Atlantic coast in the course of the field work for this report. These observations indicate that clay balls may be formed in either marine or continental environments. Their occurrence in the oil sands, therefore, does not indicate necessarily that the sands were deposited by stream currents; the clay balls may have been formed by waves on beaches.

The fine and very fine sand grains and most of the medium grains in the Bartlesville and Burbank sands are angular to subangular, but the coarser grains are subrounded to rounded. These characteristics were found to prevail also in the modern beach sands that were studied. The oil-producing sand in much of the Quincy trend (Fig. 1) in Greenwood County, Kansas, is composed largely of coarse and very coarse sand grains that are rounded and subrounded. This sand[36] is coarser than sand commonly found in wind-laid deposits, and the rounded shape of the grains is much more common than generally prevails in sediment deposited by a river, but sand having these characteristics is typical of beach deposits formed by waves and currents.

A very few marine fossils were found in the shoestring sands and in thin limestone and shale beds in the sand zone, but many were found in the beds immediately above and below the sands. Broken parts of fossil shells, too fragmentary for identification, were seen in the cuttings from beds at the horizons of the Burbank and Bartlesville sands in several wells in Osage County, Oklahoma. A few fossil fragments have been observed in well cuttings from the horizon of the Burbank sand in Kansas.

It is noteworthy that so few fossils have been observed in the Bartlesville and Burbank sands. However, it is possible that shell material in considerable amount was deposited with the sand but was dissolved by the humic acids derived from the abundant organic materials associated with the sands, or that it was dissolved by rain and river water and carried away in solution or redeposited in part in the sand as cementing material. Observations on the coasts indicate that shells are being destroyed by solution not long after they become buried in the marsh. Clams and other shells were seen in abundance by Miser and Bass in the uppermost few inches of the marsh muck on the landward side of offshore bars on the coasts of Delaware and Virginia, but no shells were found in the muck below a depth of 5–6 inches. Fishermen reported that the shells that occur a few inches below the surface of the muck are "rotten and crumble in your fin-

[36] J. A. Udden, "Mechanical Composition of Clastic Sediments," *Bull. Geol. Soc. America*, Vol. 25 (1914), p. 678.

gers." It appears probable that the humic acids released by the abundant organic material in the marsh muck dissolve the calcium carbonate of the shells and thus destroy them completely soon after burial. Branner[37] described offshore bars on the coast of Brazil in which considerable shell material has been dissolved out by rain water entering the sand from above and by river water entering the sand bodies from the lagoons.

CONCLUSIONS

The shoestring-like distribution of the belts of Burbank sand in Kansas and Oklahoma, which is established by the records of thousands of wells, restricts the sand bodies to two probable types of deposits—filled stream channels or offshore bars. Less confidence can be placed in the information about the Bartlesville sand than in that available for the Burbank sand, because there are fewer exact data concerning the distribution and shapes of the Bartlesville sand bodies. Sufficient facts were learned about the Bartlesville sand, however, to justify the assertion with confidence that it and the Burbank sand were deposited by similar agencies and under similar environments, but at different times.

The areal distribution of the sand bodies in narrow, nearly straight trends, the offset arrangement of the individual sand bodies within the trends, the gaps between the sand bodies, the occurrence of features believed to represent beach-growth ridges, the probable original seaward slope of the bases of many of the sand bodies, the narrow, elongate lens-like form and the bar shape, particularly the convex top known to characterize many of the sand bodies, the composition of the sands and their physical characters, such as sorting and shapes of grains, the types of bedding, and the occurrence of marine fossils are facts that led the writers to conclude that the Bartlesville and Burbank sands were deposited as systems of offshore bars. The depositional processes and methods of preservation of the shoestring sands are described somewhat at length in a previous paper[38] and will be set forth only briefly here. The Bartlesville sand was deposited on the western shore of an arm of the Cherokee sea that occupied parts of northeastern Oklahoma and southeastern Kansas. The writers' studies corroborate McCoy's conclusions,[39] made several years ago, that

[37] J. C. Branner, "The Stone Reefs of Brazil, their Geological and Geographical Relations," *Bull. Mus. Comparative Zool.*, Vol. 44 (1904), pp. 174–76.

[38] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1333–42.

[39] Alex W. McCoy, oral communication.

for a long period of time the western shore of the shallow Cherokee sea migrated to and fro across a relatively narrow northeastward-trending strip of country in eastern Osage, Washington, and Nowata counties, Oklahoma, and in southeastern Kansas. The Bartlesville sand lenses are believed to have been deposited during this stage of the Cherokee sea as series of offshore bars. Somewhat later the Cherokee sea expanded in northeastern Oklahoma and eastern Kansas until its western shore probably trended northward across Kay County, Oklahoma, and western Cowley and Butler counties, Kansas.

The interbedded marine and non-marine sediments of the Cherokee shale indicate that the seashore migrated many times back and forth across broad areas in eastern Kansas and northeastern Oklahoma. The trends of Burbank sand bodies are believed to have been deposited as offshore bars bordering the western shore line during one of the temporary partial withdrawals of the Cherokee sea. The data in Greenwood County indicate that Burbank sand deposition represents two stages of the Cherokee sea which have been designated the Teeter-Quincy and Sallyards Lamont stages.[40]

During the time of the Teeter-Quincy stage a system of offshore bars, represented in part by the sand bodies of the Teeter and Quincy trends and probably the Haverhill trend, was slowly built along the shore.[41] On the basis of somewhat meagre data we have tentatively assigned the sand bodies of the Burbank and South Burbank fields to this stage. The close resemblance of the ridged appearance of the sand body of the Burbank field (Fig. 13) to beach-growth lines (Figs. 8 and 12) and the arrangement of the sand bodies of the Stanley Stringer and South Burbank fields with respect to the sand body of the main Burbank field (Fig. 14) led the writers to conclude that the sand bodies of these fields are deposited as a series of overlapping barrier beaches that grew progressively by additions of sand on the east side, and that the beach produced in this manner formed the south lip of the mouth of a large bay that lay north and northwest of the Burbank field (Fig. 15). It follows that the western part of the Burbank sand body is older than the eastern part, and that the sand bodies of the Stanley Stringer and South Burbank fields are still younger. To follow the analogy further, offshore bars that were formed during the Teeter-Quincy stage along the margin of the main Chero-

——— "A Short Sketch of the Paleogeography and Historical Geology of the Mid-Continent Oil District and Its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (1921), pp. 559–61.

[40] N. W. Bass, *op. cit.*, pp. 1333–39, Figs. 13 and 15.

[41] *Ibid.*, p. 1333.

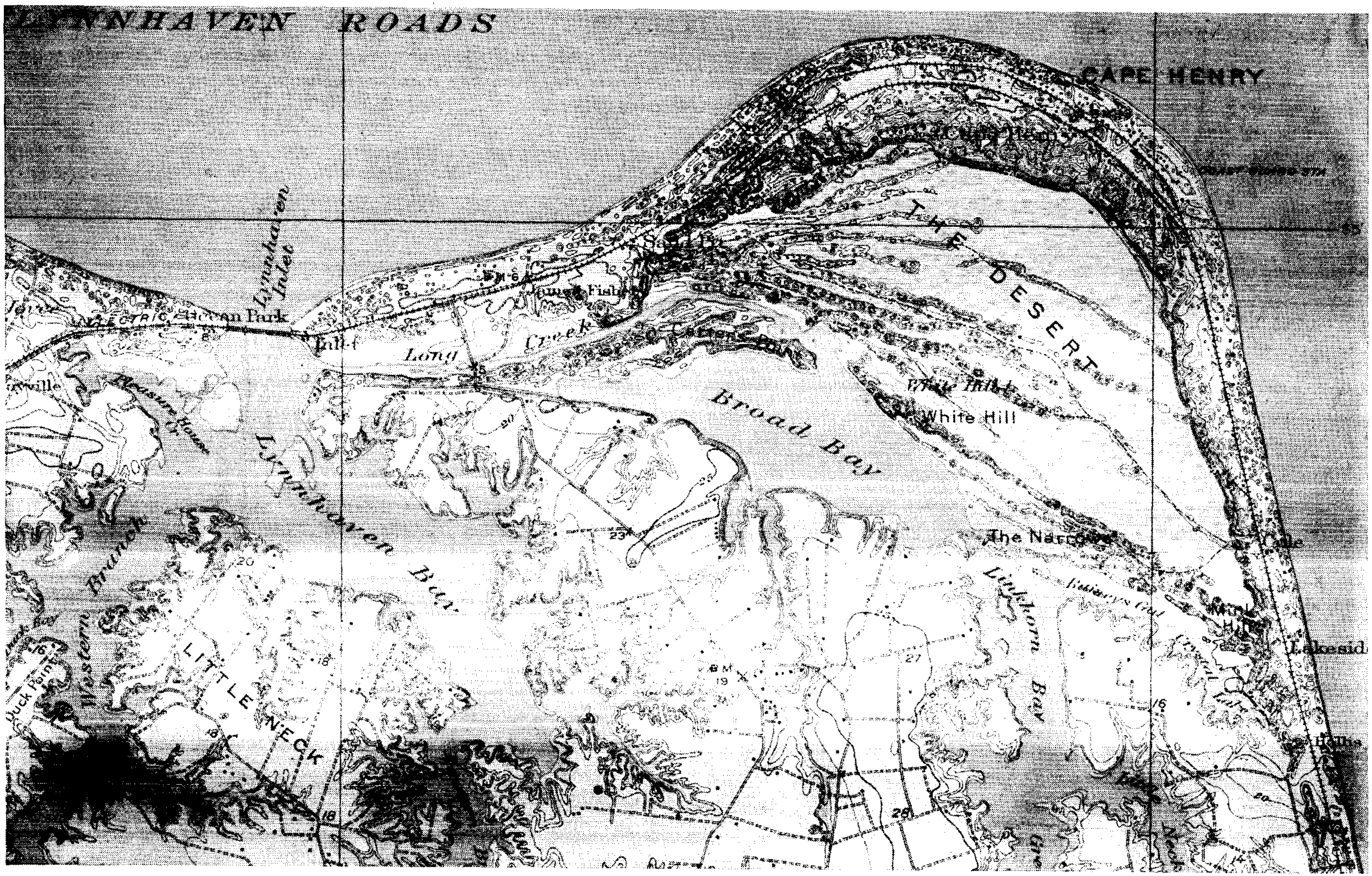

FIG. 12. Topographic map of Cape Henry, Virginia, showing ridges of sand trending approximately parallel with the shore.

FIG. 13. Map of Burbank and South Burbank oil fields showing thickness of Burbank sand as determined from well logs. Areas where sand is thickest are shown in black. Areas of thick sand have alignments that trend approximately parallel with the east, northeast, and north margins of the sand body and are believed to represent beach-growth lines. Lines connect points of equal thickness; interval between lines is 10 feet.

kee sea northward beyond the bay mouth should be separated from the Burbank field by a strip of country, possibly several miles wide, that was occupied by the bay and may therefore be devoid of good sand bodies. The absence of Burbank sand in several dry holes in this region is therefore reasonably accounted for.

Late in the Teeter-Quincy stage the shallow areas near the margins of the sea, including the lagoons and marshes that occupied the landward side of the offshore bars, were filled with sediment consisting largely of silt, organic material, clay, and very fine sand. This silting-up process pushed the shore line slightly seaward, and the marsh sedi-

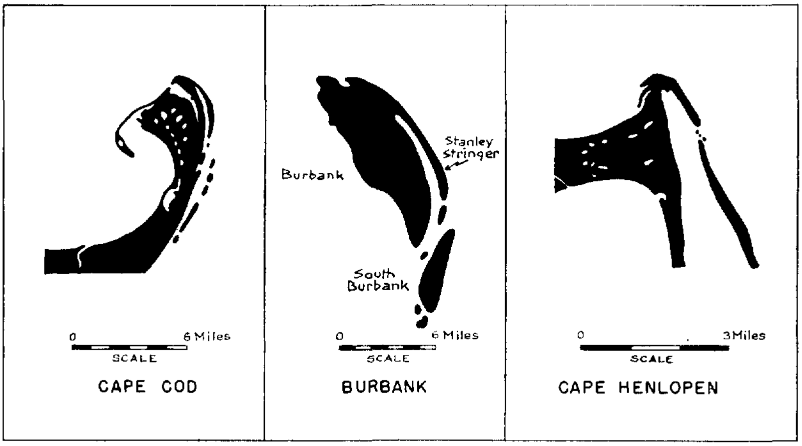

FIG. 14. Sketch maps of Cape Cod, Massachusetts, and Cape Henlopen, Delaware, showing submerged bars attached to main beach sand bodies of capes, and of sand bodies of main Burbank oil field, attached Stanley Stringer, and South Burbank oil field. Main sand bodies of Cape Cod and Cape Henlopen contain parallel ridges representing beach-growth lines.

ment encroached upon the offshore bars and buried them, at least in part. It is suggested that late in the Teeter-Quincy stage a slight subsidence of the trough of the Cherokee basin, which lay in easternmost Kansas and eastern Oklahoma,[42] accompanied by an uplift of a few feet in the Nemaha granite ridge area, which was only 10–20 miles west of the western shore line, caused an eastward tilting of much of eastern Kansas and probably northeastern Oklahoma. This slight crustal movement, together with the partial filling of the near-shore areas with sediment, shifted the western shore line of the Cherokee

[42] N. W. Bass, L. E. Kennedy, W. R. Dillard, and Constance Leatherock, "Subsurface Geology of Osage County, Oklahoma," *U.S. Dept. Interior Press Mem. 105368* (January, 1936), Pl. 1-A—"Sketch Map Showing the Thickness of the Cherokee Shale in Parts of Northeastern Oklahoma and Eastern Kansas."

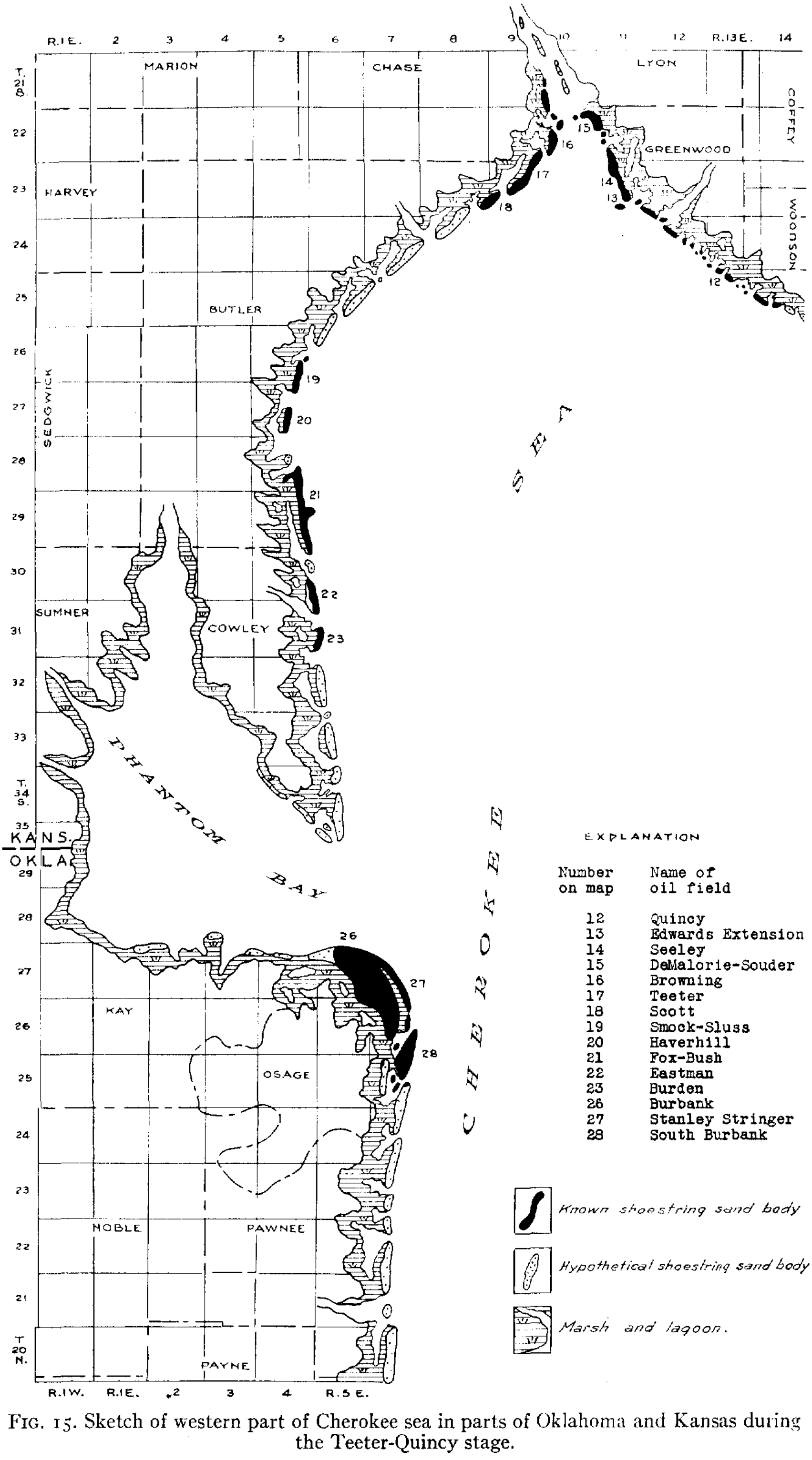

FIG. 15. Sketch of western part of Cherokee sea in parts of Oklahoma and Kansas during the Teeter-Quincy stage.

sea in Kansas a few miles eastward, but its effect in northern Oklahoma has not been determined with certainty. An elevation or depression of the shore of only a few feet would have shifted the lateral position of the shore line several miles, because the land area bordering the Cherokee sea was probably a coastal plain of extremely low relief, the sea was very shallow, and the slope of the near-shore sea bottom had a very gentle gradient. Consequently, a crustal movement of very slight magnitude would have produced the results suggested by the distribution of the shoestring-sand trends in Kansas.

As more fully described in an earlier paper,[43] the Sallyards-Lamont stage of the Cherokee sea followed the eastward shifting of the seashore lines, and during this stage the sea again built along its shore a system of offshore bars, including the sand bodies of the Sallyards and Lamont trends in Kansas (Fig. 1). The available data are insufficient to show the extension of the shore line of the Sallyards-Lamont stage into Oklahoma. A projection of the Sallyards trend (Fig. 1) of this stage southwestward through southeastern Butler County and western Cowley County, Kansas, into the Rainbow Bend field and thence nearly due south toward Oklahoma has considerable merit but involves also several serious objections. Such a scheme necessitates that the sand bodies of the Eastman and Burden fields and other sand bodies that are believed to exist in Cowley County (Fig. 15), which it appears were formed during the earlier Teeter-Quincy stage, should have remained far out at sea during the later Sallyards-Lamont stage. It seems highly probable that if left in such an environment these sand bodies would have been at least partly if not wholly destroyed by the waves and currents. The true relations of the old shore lines in southern Butler and Cowley counties, Kansas, and northern Kay and Osage counties, Oklahoma, will have to await the drilling of more wells that will reveal additional facts concerning the distribution of the sand bodies in this region.

It is truly remarkable that perishable features such as offshore bars could be preserved in such completeness as is exhibited by the belts of Burbank and Bartlesville sand bodies. The offshore bars along present-day coasts are transitory features that are modified by every storm. When the sea encroaches upon the land its waves and currents continually erode the offshore bars and drive them inland. It is probable, therefore, that an advancing sea does not create conditions conducive to the preservation of its shore features. On the other hand, if the land is being extended seaward, conditions favorable for preservation of beach deposits should be developed. There are many localities

[43] N. W. Bass, *op. cit.*, pp. 1337–39.

on the Atlantic coast of Florida,[44] North Carolina,[45] Massachusetts,[46] and elsewhere where recent offshore bars have been formed a short distance seaward from old offshore bars and have inclosed the old bars in the midst of the lagoons that lie on the landward side of the new offshore bars. One such locality is illustrated in Figure 17. The formation of the new bars extends the land seaward, and the old bars are slowly buried in the silt and organic sediment that accumulate in the lagoons. In time the old bars are completely buried. Therefore, it is

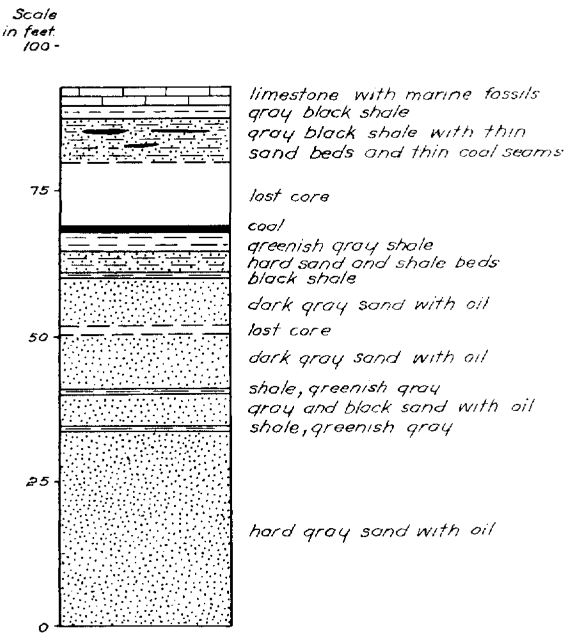

FIG. 16. Record of core from upper part of Bartlesville sand and overlying beds in Pershing oil field, Osage County, Oklahoma.

probable that the ancient Bartlesville and Burbank sand belts were buried by encroachments of the land upon the Cherokee sea in Kansas and Oklahoma rather than by deposits from an expanding sea. The dominant movement of the Cherokee sea was one of expansion upon the land, but the character of the sediments indicates that the ad-

[44] *U. S. Coast and Geodetic Survey Coast Charts 1245 and 1246.*
N. S. Shaler, "The Geological History of Harbors," *U. S. Geol. Survey 13th Ann. Rept.*, Pt. 2 (1893), p. 187.

[45] *U. S. Coast and Geodetic Survey Coast Chart 1235.*

[46] N. S. Shaler, "Sea-coast Swamps of the Eastern United States," *U. S. Geol. Survey 6th Ann. Rept.* (1885), p. 382.

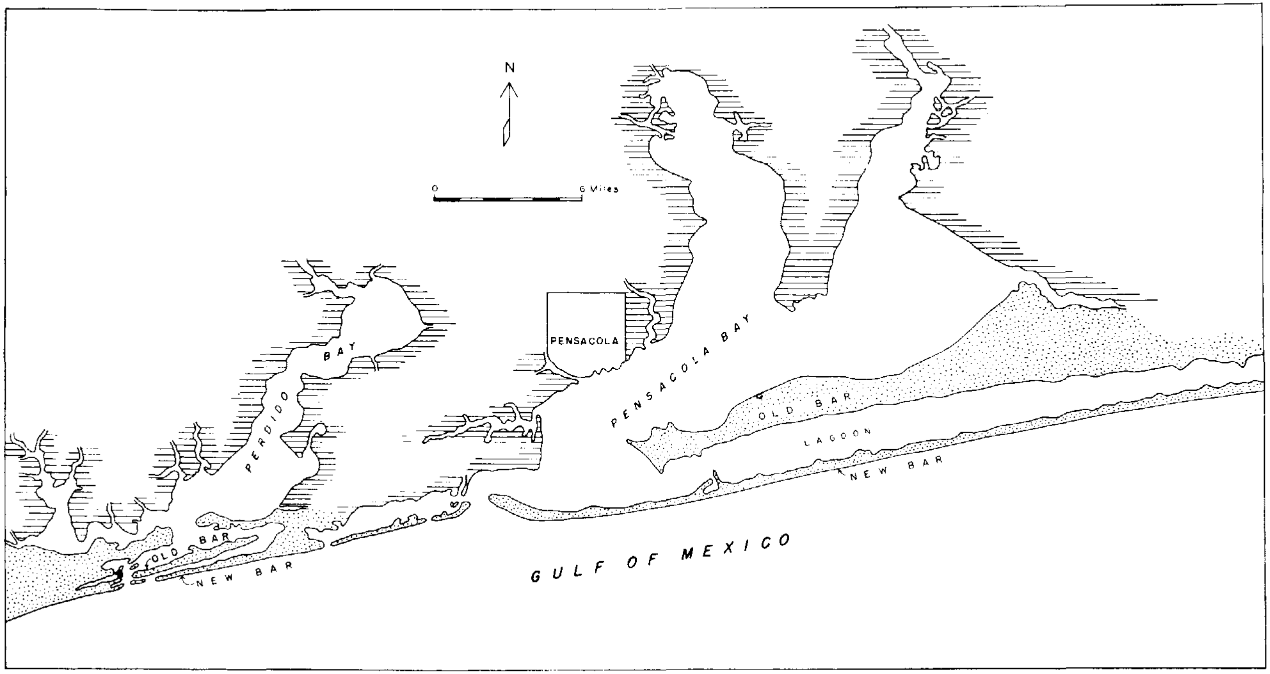

FIG. 17. Sketch of part of Gulf coast of Florida (*after U. S. Coast and Geodetic Survey Chart 1265*), showing old offshore bars inclosed by lagoons formed behind new bars.

vance was accompanied by many temporary halts and reversals. The writers believe that it was during some of these intervening periods that the Bartlesville and Burbank sands were formed and buried.

Nature's processes are seldom simple, however. The offshore bars on the Atlantic coast are in almost constant change; the ocean waves and currents erode the beaches in places and expand them in others.[47] Locally the sea pushes offshore bars landward over the marsh, exposing thick layers of marsh muck on the seashore.[48] Near-by, growth ridges on the beach prove that there the sea has recently built the beach seaward. Moreover, the processes are repeatedly reversed. Erosion will prevail for a time, and in the same locality deposition will take place at other times. Most offshore bars are being extended at one end and destroyed at the other; that is, the inlets between the bars are migrating along the coast in the direction of the longshore currents.[49]

The detailed data supplied by cores and cuttings of the Bartlesville and Burbank sands indicate that their environment of deposition was as changeable as that on the coasts of to-day. A thick zone of clean quartz sand, such as that shown in the lower part of the core record of the Bartlesville sand given in Figure 16, probably represents the middle part of an offshore bar that accumulated along a narrow strip of the coast where conditions were stable for a long time. Beds of black carbonaceous shale, which are common in the Bartlesville and Burbank sands, indicate that for short periods the marshes locally encroached upon the beaches. The occurrence of beds of sandy shale and thin beds of limestone containing marine fossils shows that for short periods the Cherokee sea spread upon the land, and that although the waves scoured the sea bottom and probably leveled off and destroyed the upper parts of the recently built offshore bars they did not destroy the bars completely. Bartlesville or Burbank sand bodies whose upper beds locally extend laterally over a broader area than the lower beds depart from the ideal bar shape, which has a wide, flat base and a narrow, convex top. A recently found example occurs in the SE. ¼ of Sec. 26, T. 26 N., R. 6 E., in the northeasternmost part of the sand body of the South Burbank field. Such a feature, if developed on the seaward side of a sand body, probably represents beach deposits formed during a minor seaward advance of the shore line, but if it is on

[47] W. J. Barden, "Wrightsville Beach, North Carolina," *Report of Beach Erosion Board, U. S. War Dept., House Document No. 218, 73rd Congress 2nd Session* (1934), Plate II.

D. W. Johnson, *op. cit.*, p. 382.

[48] W. M. Davis, "Geographical Essays," edited by D. W. Johnson (1909), p. 709.

[49] D. W. Johnson, *op. cit.* (1919), p. 374.

the landward side it records a minor advance of the beach upon the marsh. Local occurrences of thin beds of fossiliferous limestone near the margins of some of the sand bodies of Kansas and Oklahoma appear to represent deposits formed during minor advances of the sea.

The coal beds found above the sand bodies, such as are illustrated by the core record in Figure 16, indicate that as the sea built bars along its shore progressively on the seaward side the fresh-water swamps, which no doubt occupied parts of the low coastal plain, followed seaward as the coastal plain was extended, until they actually lay above the site of the earlier beach. The fossiliferous limestone shown at the top of the core represents deposition at a much later time, after the sea had again encroached far upon the land. The fossiliferous Inola limestone, which occurs above the Bartlesville sand in wells and above the Bluejacket sandstone on the outcrops, and the fossiliferous limestone beds that occur above the Burbank sand in western Osage County and may represent the Pink lime were probably deposited in this manner.

SUGGESTIONS FOR LOCATING NEW SHOESTRING-SAND OIL FIELDS

The sketch map, Figure 15, is intended to call attention to an interpretation that might be used as a guide to prospect a part of the undeveloped territory containing the Burbank sand bodies. The writers have purposely not attempted to place the hypothetical sand bodies, shown by the dotted pattern, with reference to dry holes that found sand. The map merely represents a scheme that they would greatly refine and then consider if they were to attempt to prospect the region. Figure 15 represents the coast line during the Teeter-Quincy stage of the Cherokee sea, which is the earlier of two stages of Burbank sand deposition determined by the study of the sand trends in Greenwood County, Kansas,[50] and expanded into Cowley County, Kansas, and northern Oklahoma by the writers' later work. The fact that the sand bodies of the Burbank, Stanley Stringer, and South Burbank fields have several features that are similar to those of Cape Henry, Virginia, on Chesapeake Bay, led the writers to place the large Phantom Bay north and northwest of the Burbank field, in approximately the same relative position with respect to the Burbank sand body that Chesapeake Bay holds to Cape Henry (Fig. 4). Although no facts are available that would establish the relationship of the sand bodies of the widely separated areas of northwestern Green-

[50] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1326, 1333–39.

wood County and south-central Butler County, the interpretation presented in Figure 15 tentatively places the sand bodies of the Smock-Sluss, Haverhill, and other fields south of these in the same stage of deposition as the Scott, Teeter, and Browning oil fields.

The southward extension of the South Burbank trend shown in Figure 15 is probably the most attractive area for prospecting. Prospecting in central Cowley County, Kansas, in the southward extension of the trend formed by the Eastman and Burden pools, also shown in Figure 15, should discover additional oil pools. Localities such as the trend across northeastern Butler County, shown in Figure 15, and a southward projection from the Rainbow Bend field, shown in Figure 1, are obviously prospectively valuable areas for oil and gas. The sand body of the Naval Reserve oil field in west-central Osage County, Oklahoma, does not appear in Figure 15, although the expansion of the field north and south is expected. It is probable that the sand body of the Naval Reserve field was deposited at a slightly different time (possibly later) than the sand of the South Burbank field, but its exact relation to the other sand bodies is not yet known.

In conclusion, the writers would like to caution operators to prospect in a projection of an established sand trend rather than in areas to the right or left of a trend; to remember that offshore bars and the undeveloped shoestring-sand bodies commonly have an established offset arrangement, and that there are gaps in modern offshore bars and barren spots between the developed shoestring-sand bodies; and that the information disclosed by the developed oil fields overwhelmingly indicates that the shoestring-sand bodies were deposited as offshore bars and prospectors should therefore expect them to occur in systems or trends that exhibit features strikingly similar to the modern offshore bars on the Atlantic coast. Features of modern bars are admirably shown by the United States Coast and Geodetic Survey's coast charts of the Atlantic and Gulf coasts. These charts have been found exceedingly helpful in this study.